NUMI Off-Axis Beam (OAB) Possibilities

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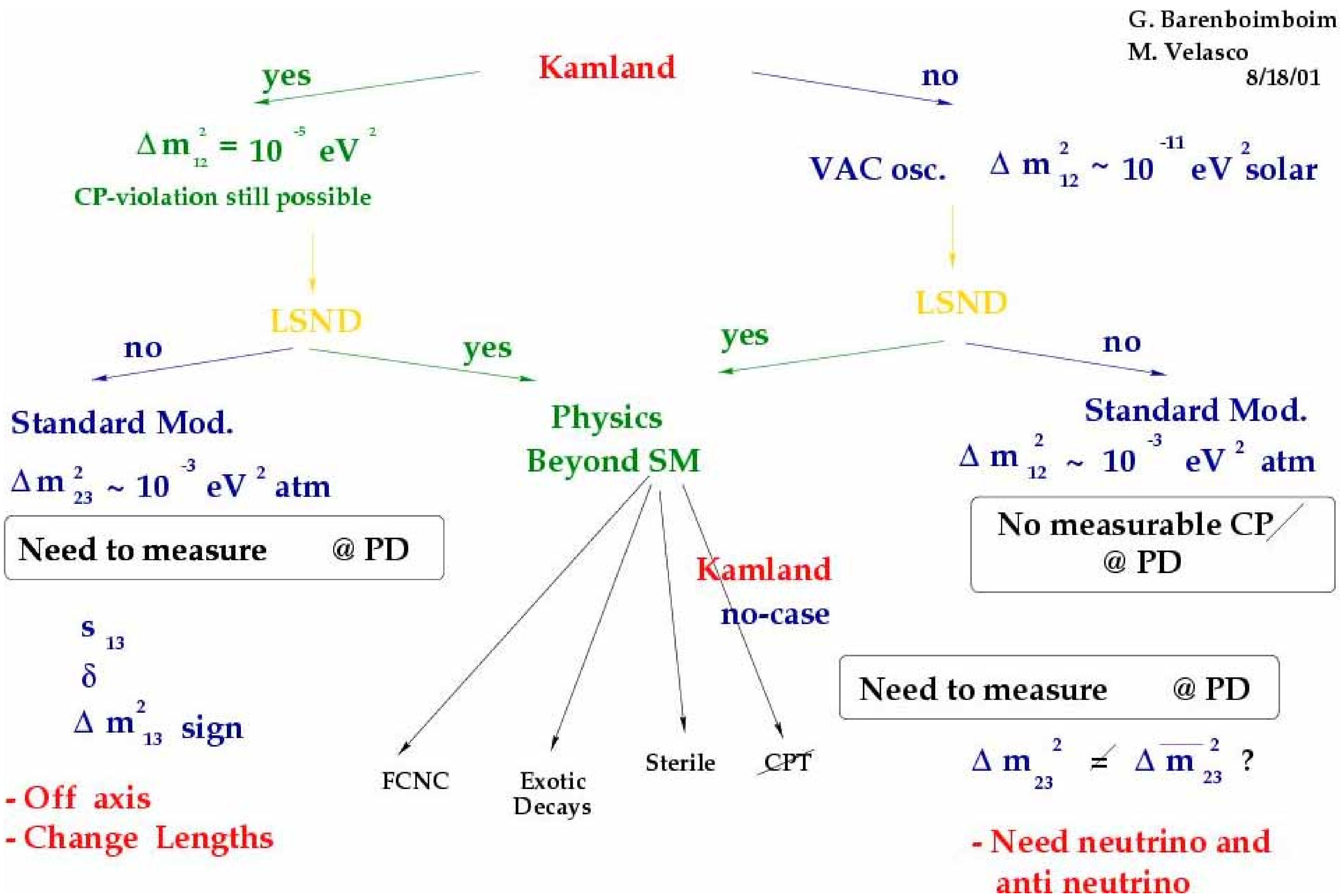
- OAB with NUMI as IS…
- OAB with NUMI upgrade it with a stronger proton source …Proton Driver (PD)

My Personal Physics time line…



Proton Driver

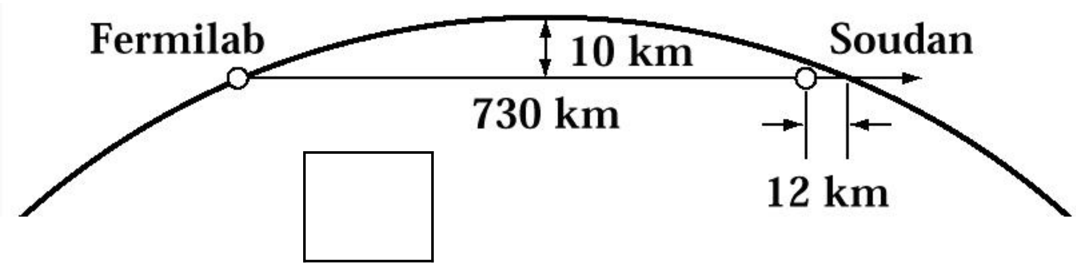
Several designs available:

http://www-bd.fnal.gov/pdriver/

The proton driver is a high intensity rapid cycling Proton synchroton. I will serve four purposes:

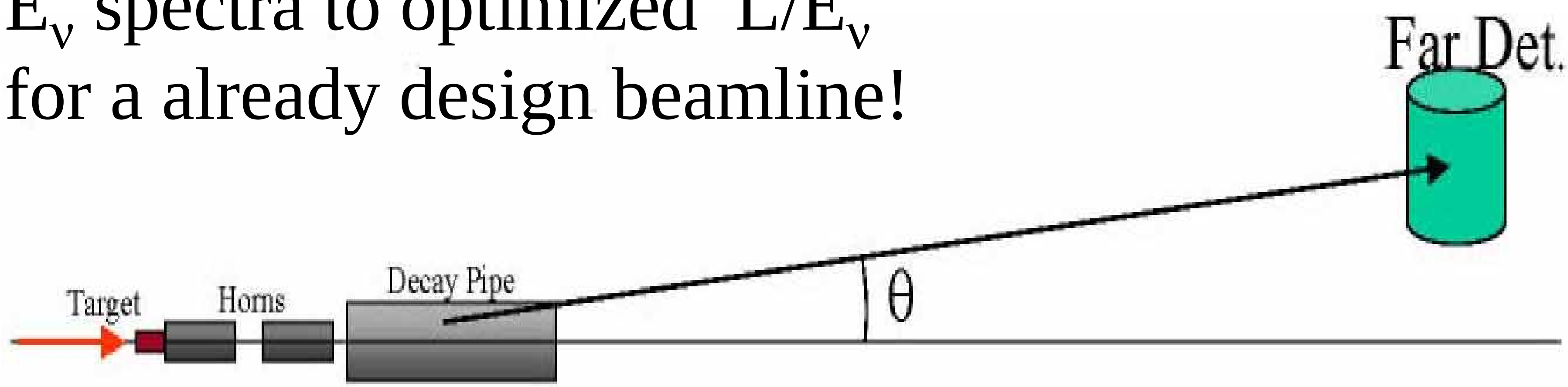
(1) To increase the Main Injector beam intensity By a factor of 3-4;

What we mean by OAB ?



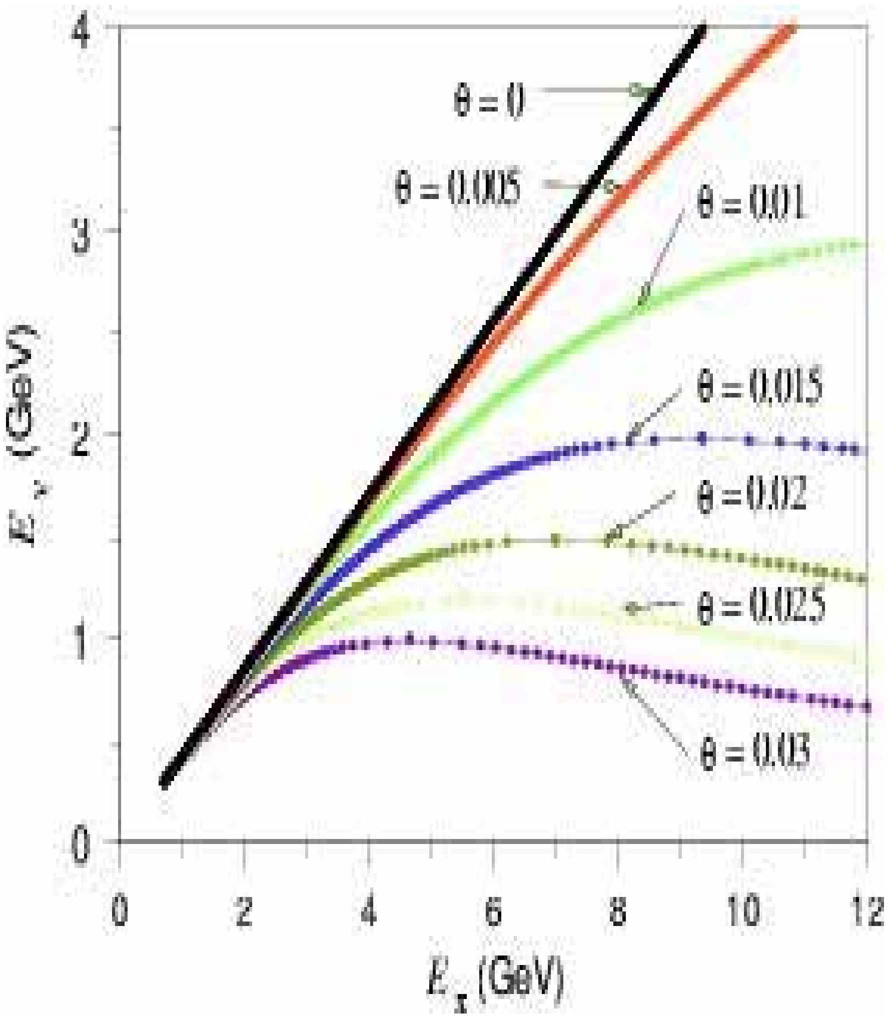
NUMI: p 120 GeV
0.4 MW
NUMI+PD: 1.6 MW

Off Axis allows us to change E_ν spectra to optimized L/E_ν for a already design beamline!



Why we like it?

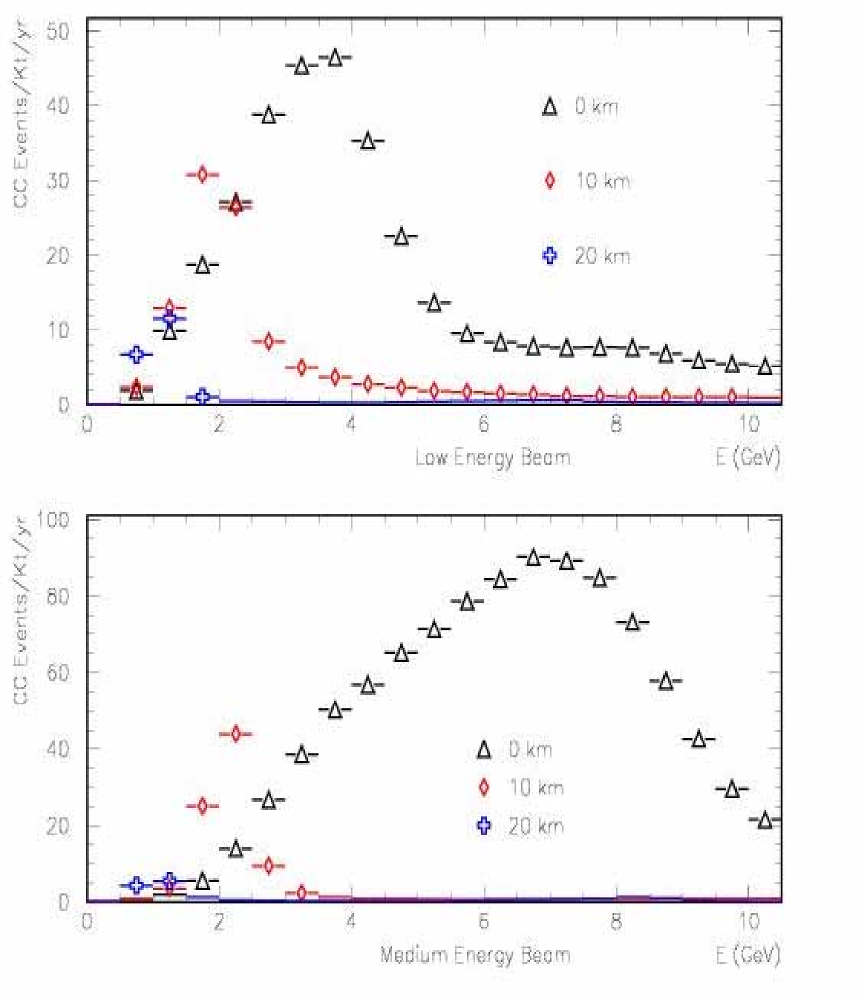
- Well defined E_ν
- Lower High E_ν tails
- Higher luminosity at E_ν-peak



E_ν= (30-50 MeV)/θ:

θ(mrad)	E_ν (GeV)
13.6	2.2 - 3.6
20.0	1.5 - 2.5
27.0	1.1 – 1.85

OAB for NUMI LE and ME (735km)

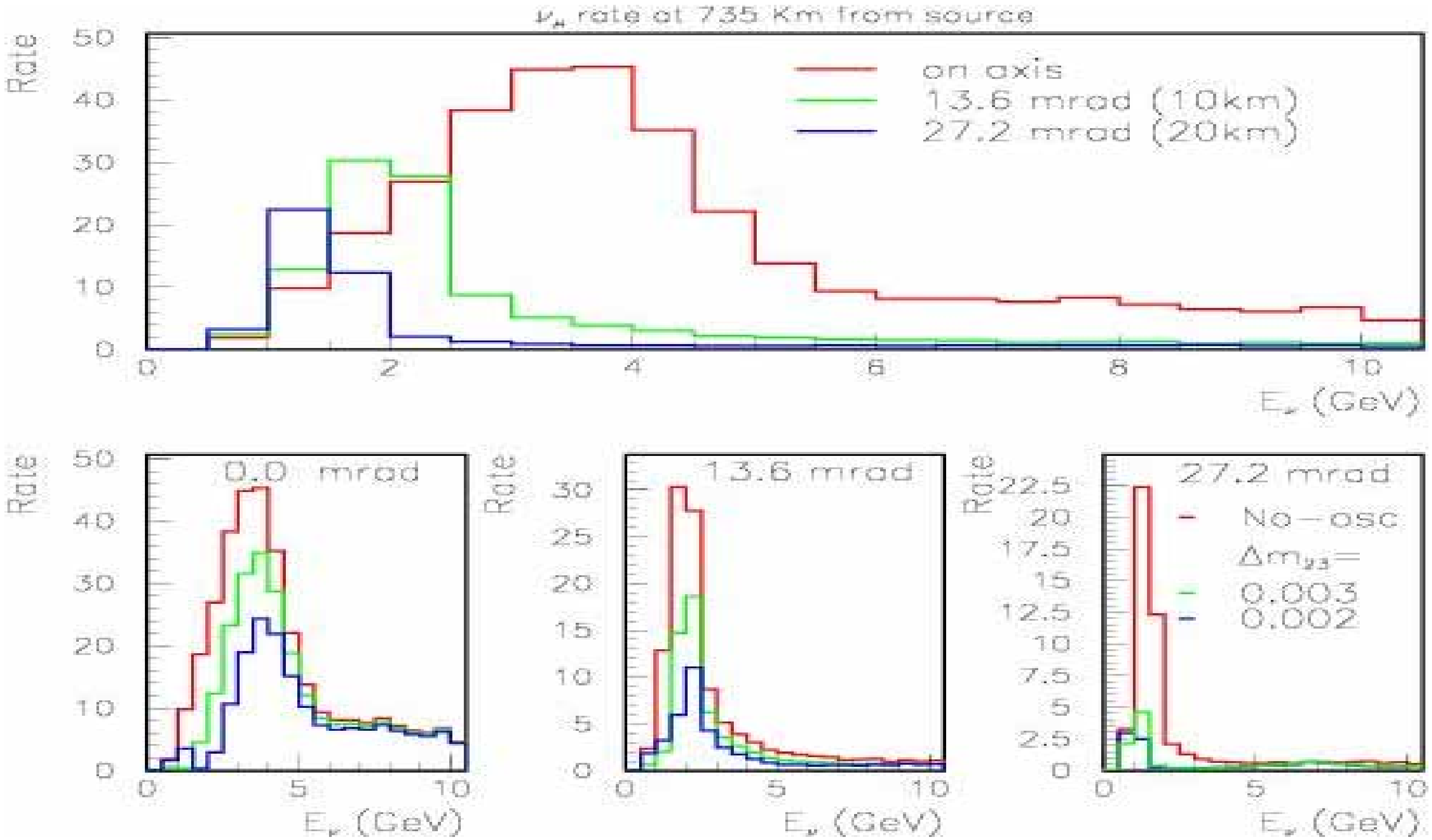


CC ν_μ

Low Energy

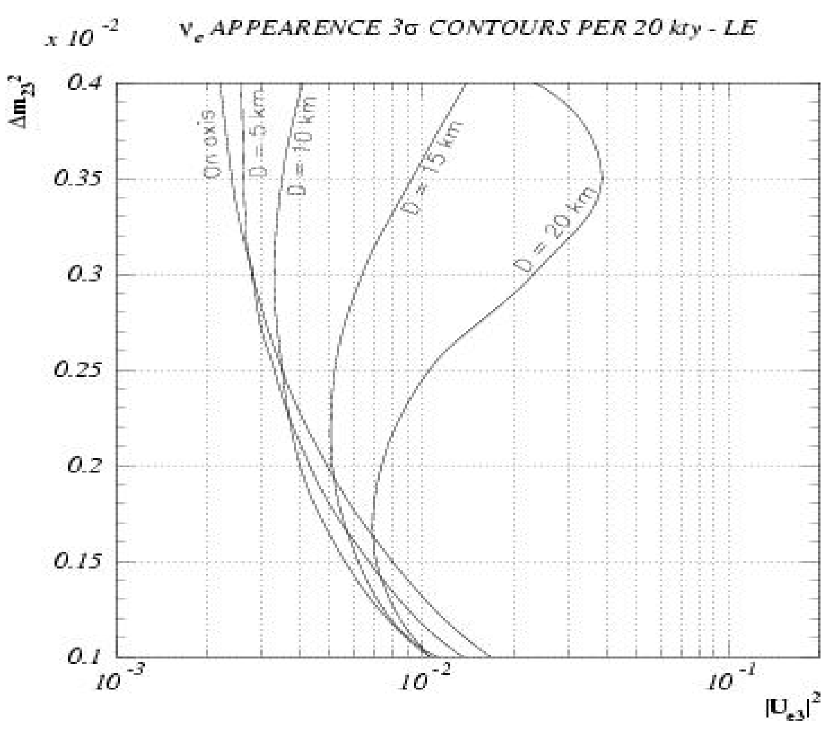
Medium Energy

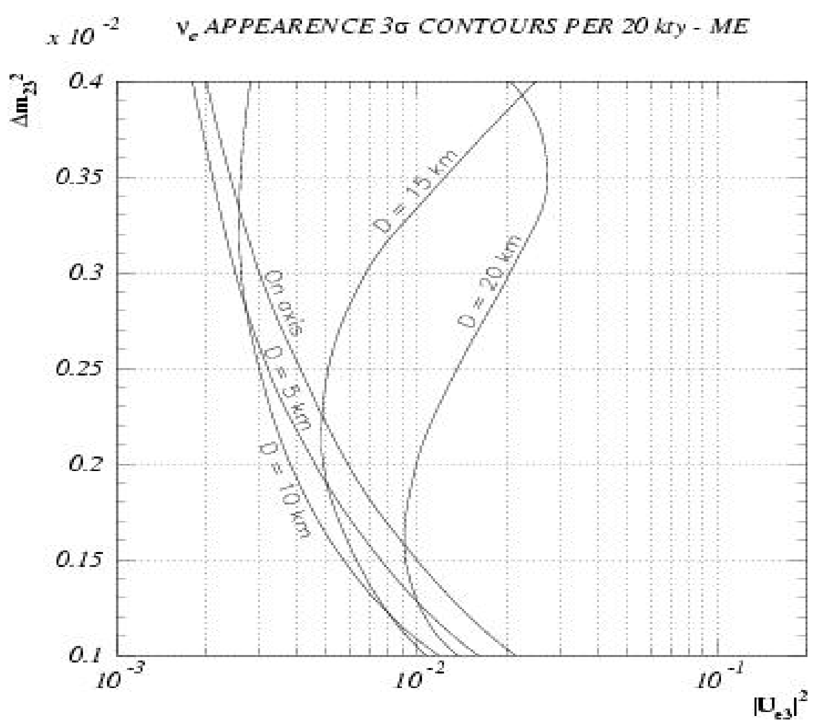
What happens in case of oscillations?



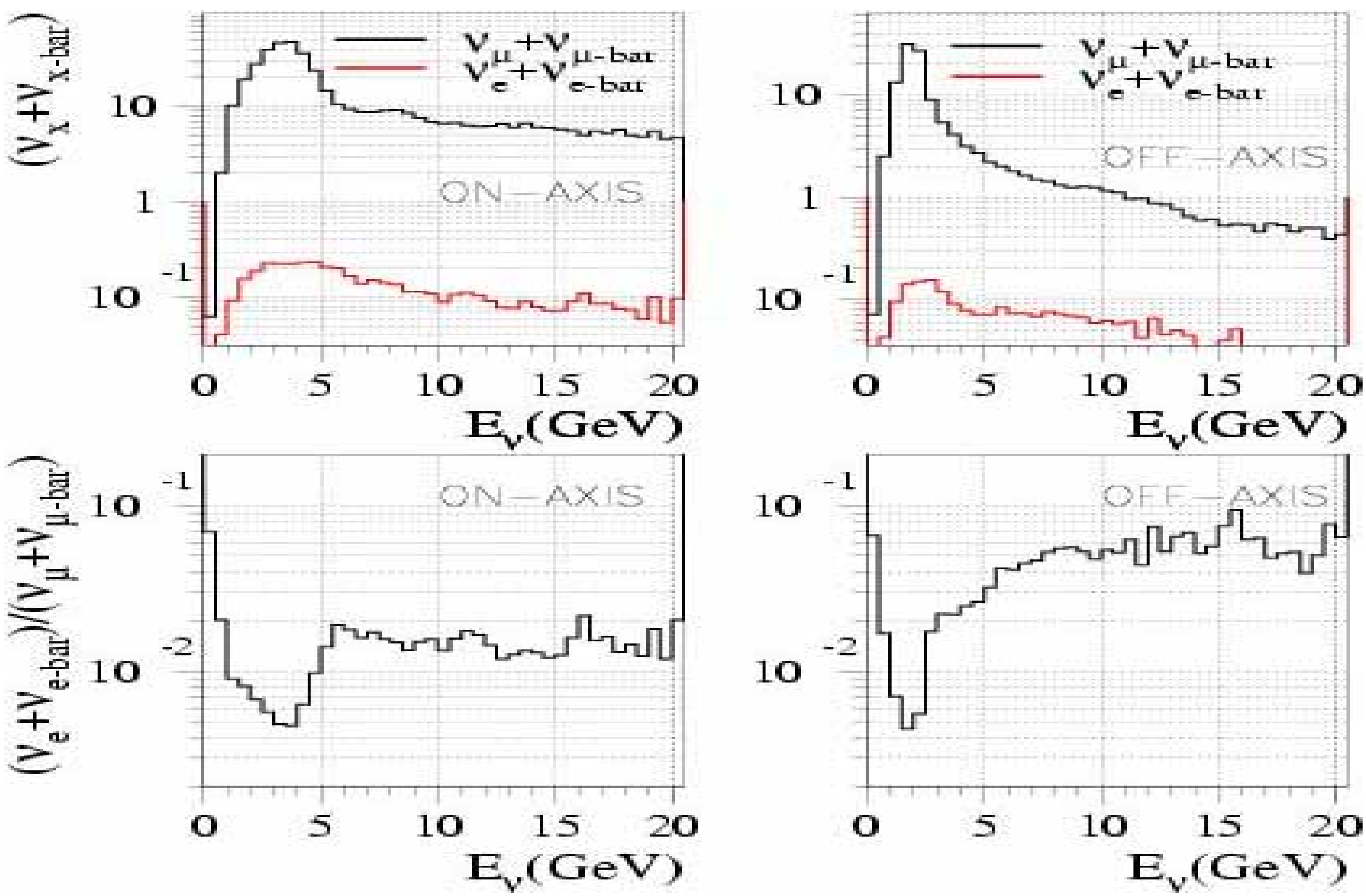
What is better for $\nu_{\mu} \rightarrow \nu_e$ appearance LE or ME?

- Assume ν_e CC 100% reconstruction efficiency
- No Background, ν_e in beamline
- 3σ signal observation:





We have to keep in mind the beam composition (OAB=10km)



Strawman 50 kt UHS Fe-Scint ν Detector

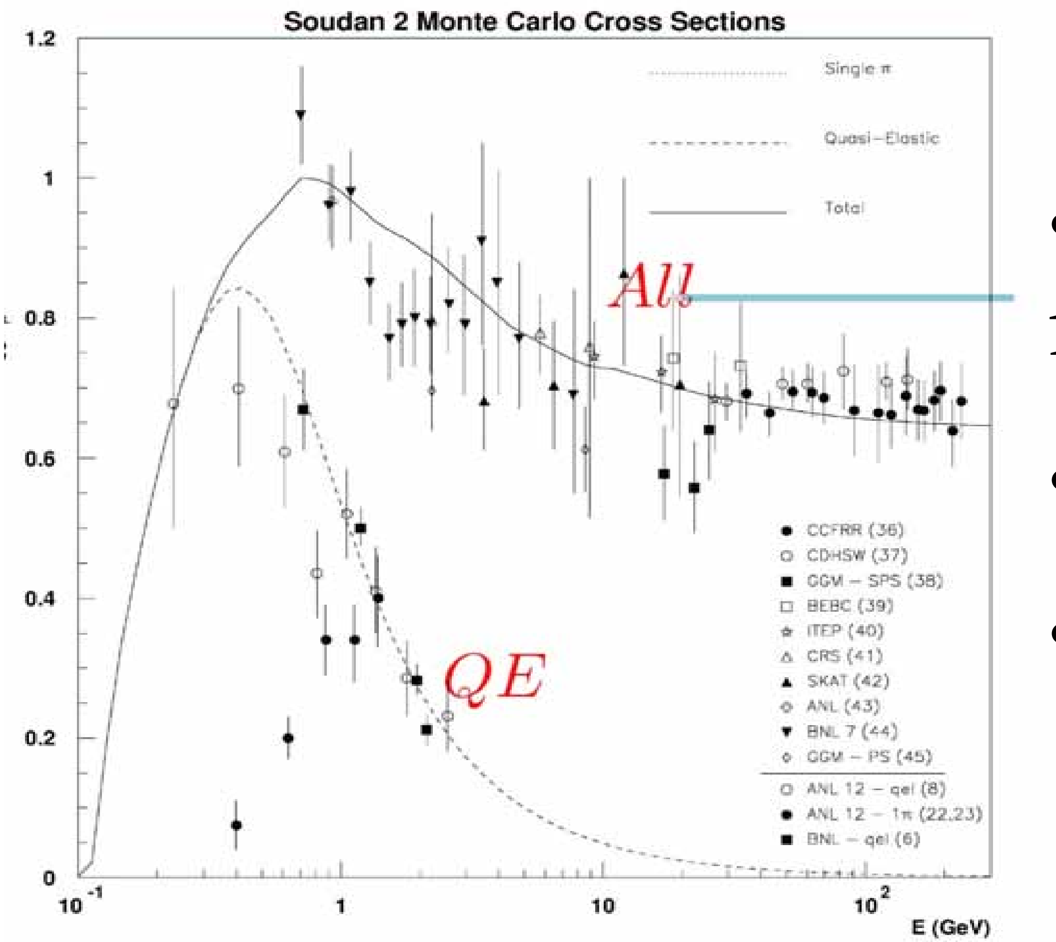
- A detector with 10X the fiducial mass of MINOS
- $\frac{1}{8}$-$\frac{1}{4}$ X_0 longitudinal sampling (2.2-4.4mm Fe - ≈ 5-10 X MINOS)
- 1 cm transverse segmentation
  - 1 cm base triangles - yields about 1 mm position resolution for mips
    - From D0 preshower test data

- This begins to look like a magnetized Soudan with much better energy resolution
- What does this imply?
  - Scintillator
    - 0.3 kt → 12 kt (24)
  - Steel
    - Straightforward extrapolation
  - Photodetector
    - 1.5 $X10^5$ fibers → 25 (50) X 10^6!
      - Note: MINOS reads out both ends of the fiber and then multiplexes fiber to photodetector 4:1
      - This example is non-multiplexed

Fe: 4.4 mm vs 2.54 cm @ MINOS

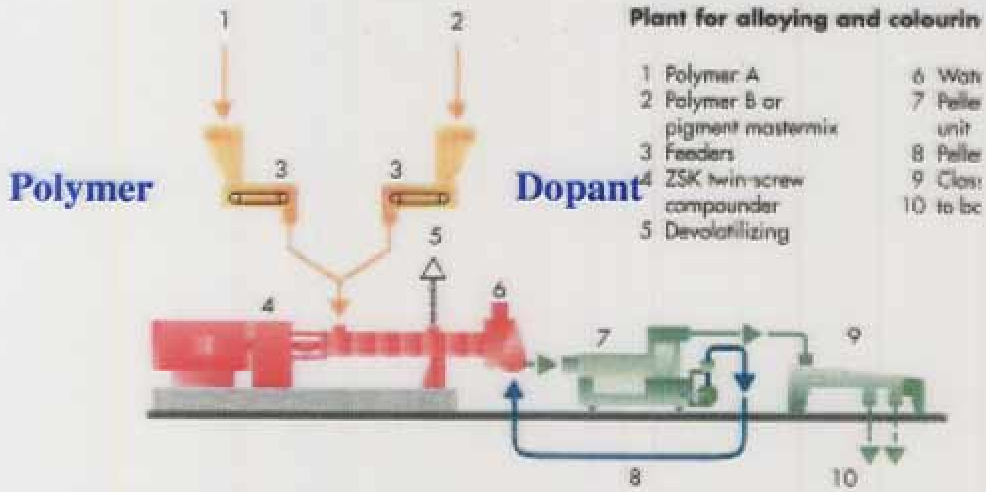
cells: 1 cm vs 4 cm @ MINOS

NUMI
(L=735 km, OAB 10 km)



- Invest in detector for QE
- $E_\nu < 2.5$GeV
- 10 Km (13.7 mrad)

Fermilab Facility



- All equipment for basic system has been specified
  - Up to 4X the production rate of MINOS
  - Expect better quality/uniformity
  - Some cost reduction over MINOS
    - ≤ $5/kg?
  - Can extrapolate to many kt with outside vendor involvement

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Detector Optimization

- All of this indicates that the light yield for Fe-Scintillator detector with VLPC readout will be very high!
    - Even with 0.4 mm fiber - estimate at this time that the yield would be higher than MINOS baseline at all positions up to 8-10m fiber length.
- This has an enormous impact on fiber cost
    - For example - MINOS
        - $4M is reduced to roughly $450k
- The same is true for the photodetector
    - A 5 X 10 element array (.4mm) would cost the same as D0's 2 X 4 element array (1mm) - ≈$240

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Detector to be consider for θ_{13} measurements

	Water Cherenkov	MINOS *	Segmented MINOS **
Signal CC nu_e	0.7 – 0.5	0.3	0.22***
Background NC	0.02 – 0.04	0.015	<0.005 (0.002)****

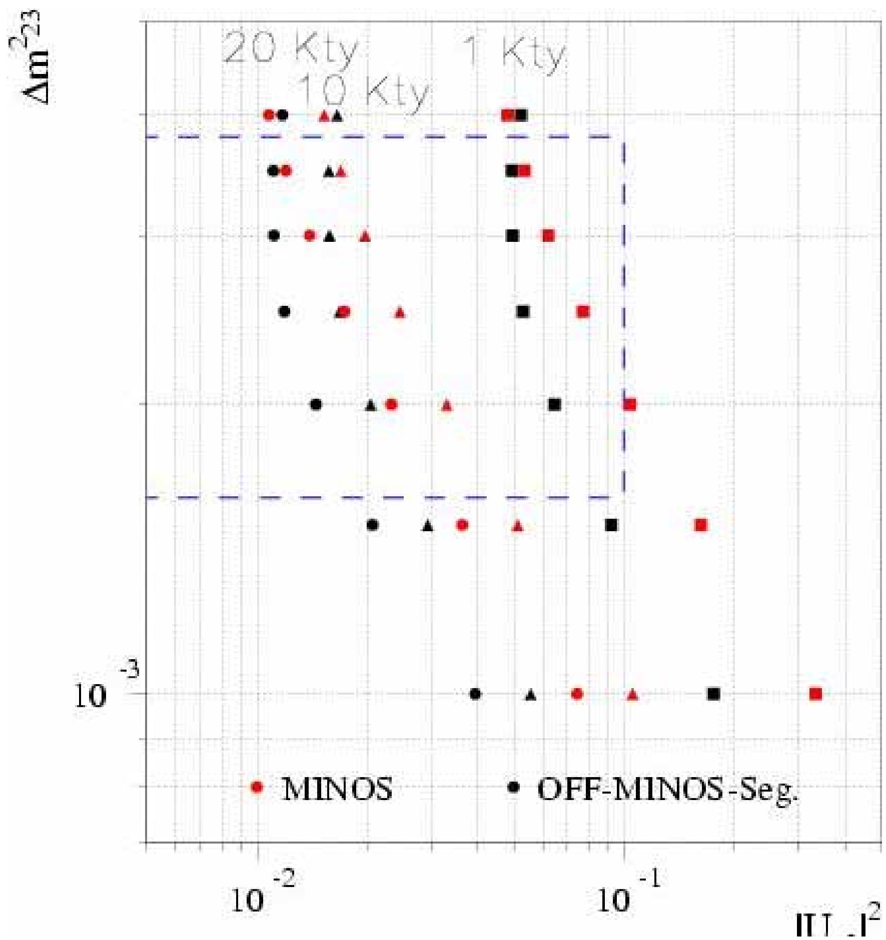
*2.54 steel & 4 cm cells

** 0.45 steel & 2 cm cells

*** Preliminary

**** OAB at 10 Km

Comparison of MINOS and SEGMENTED-OFF-MINOS (SO-MINOS)



- SO-MINOS has Better Figure-of Merit than MINOS for Δm_{23}^2~0.003 eV^2 (statistical error):

FOM for SO-MINOS 2 times better than MINOS

SO-MINOS and MINOS for $\Delta m_{23}^2 = 0.003\ eV^2$ and $|U_{e3}|^2 = 0.01$

Assume 1Kton*year

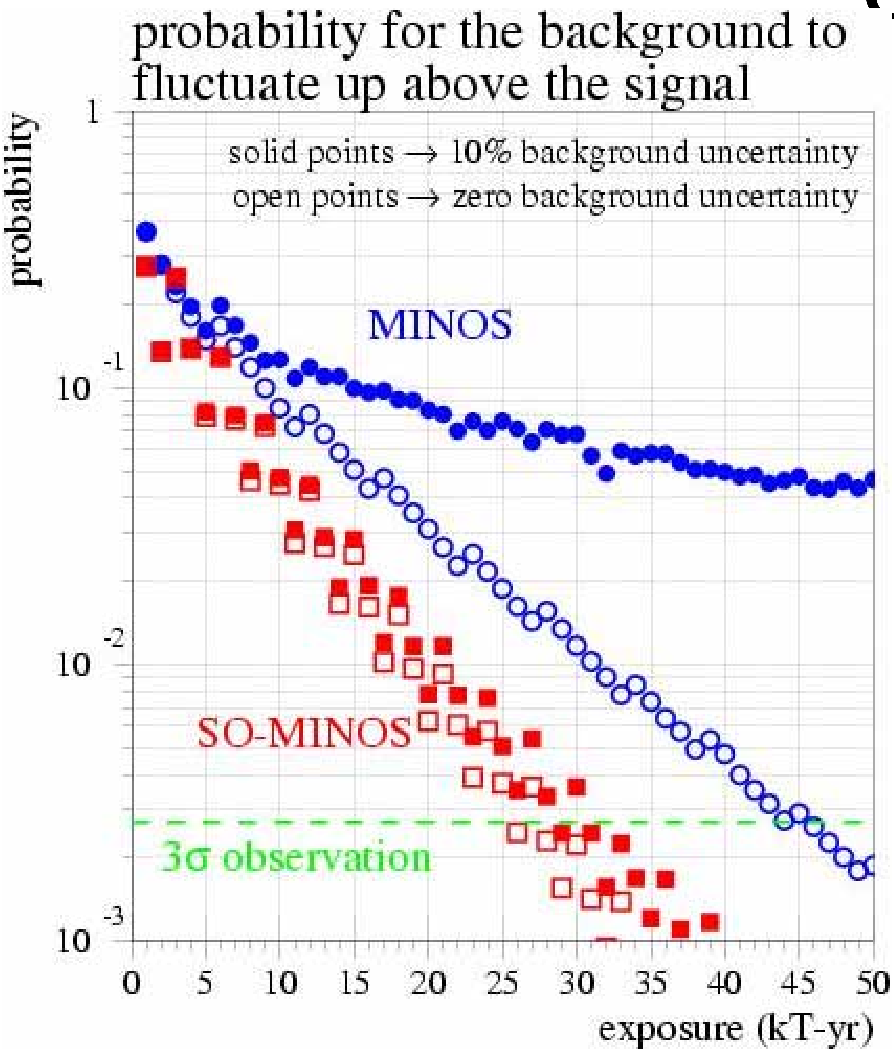
FOM=S/Sqrt(BG)

Exp.	Signal	ν_e CC	ν_μ CC	ν_τ CC	NC	Tot. BG
MINOS	0.85	0.56	0.39	0.3	2.73	3.97
SO MINOS	0.29	0.15	0.0	0.0	0.05	0.20

$FMO_{SOMINOS} = 0.66$

$FMO_{MINOS} = 0.44$

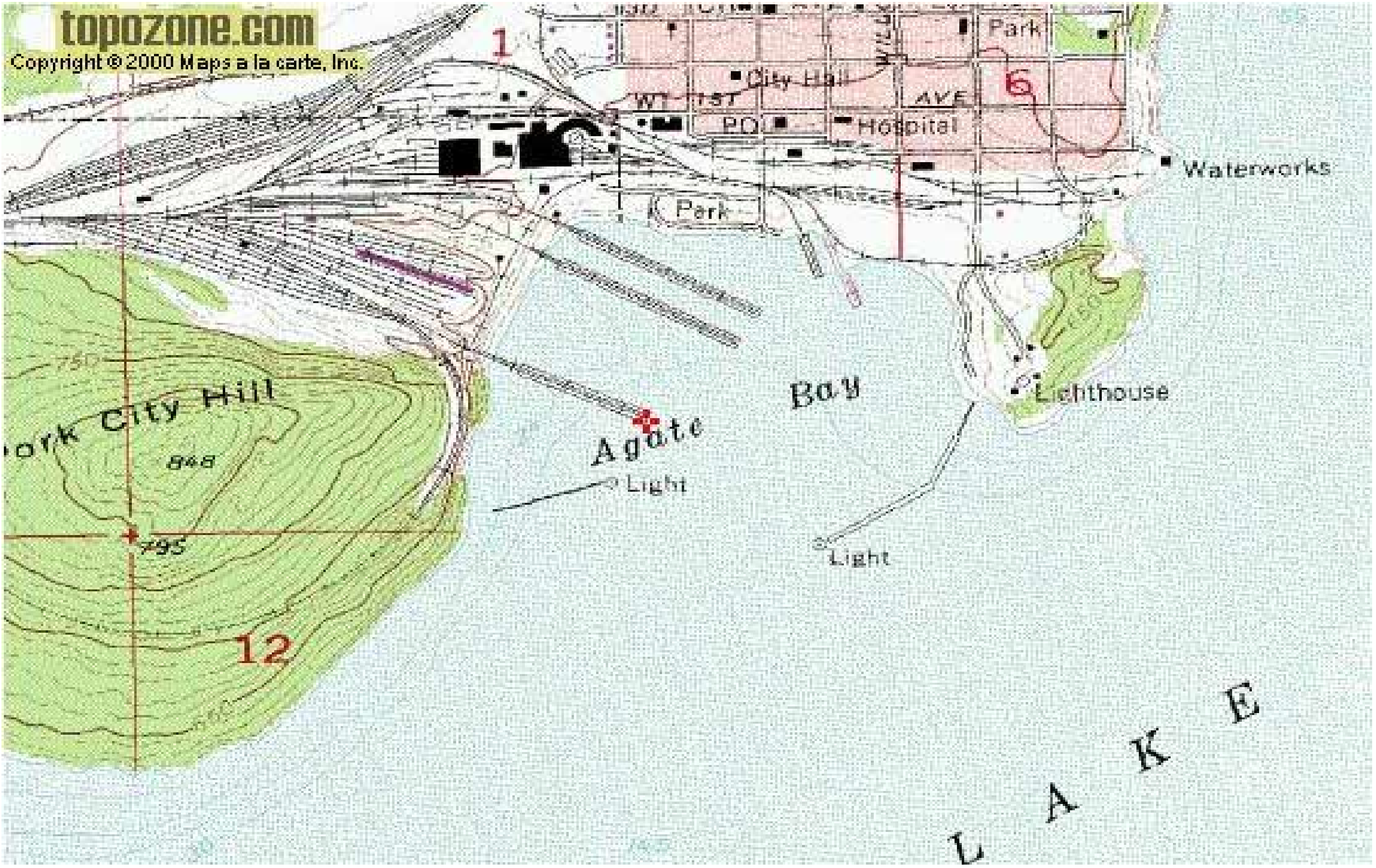
Observation Probability for this case



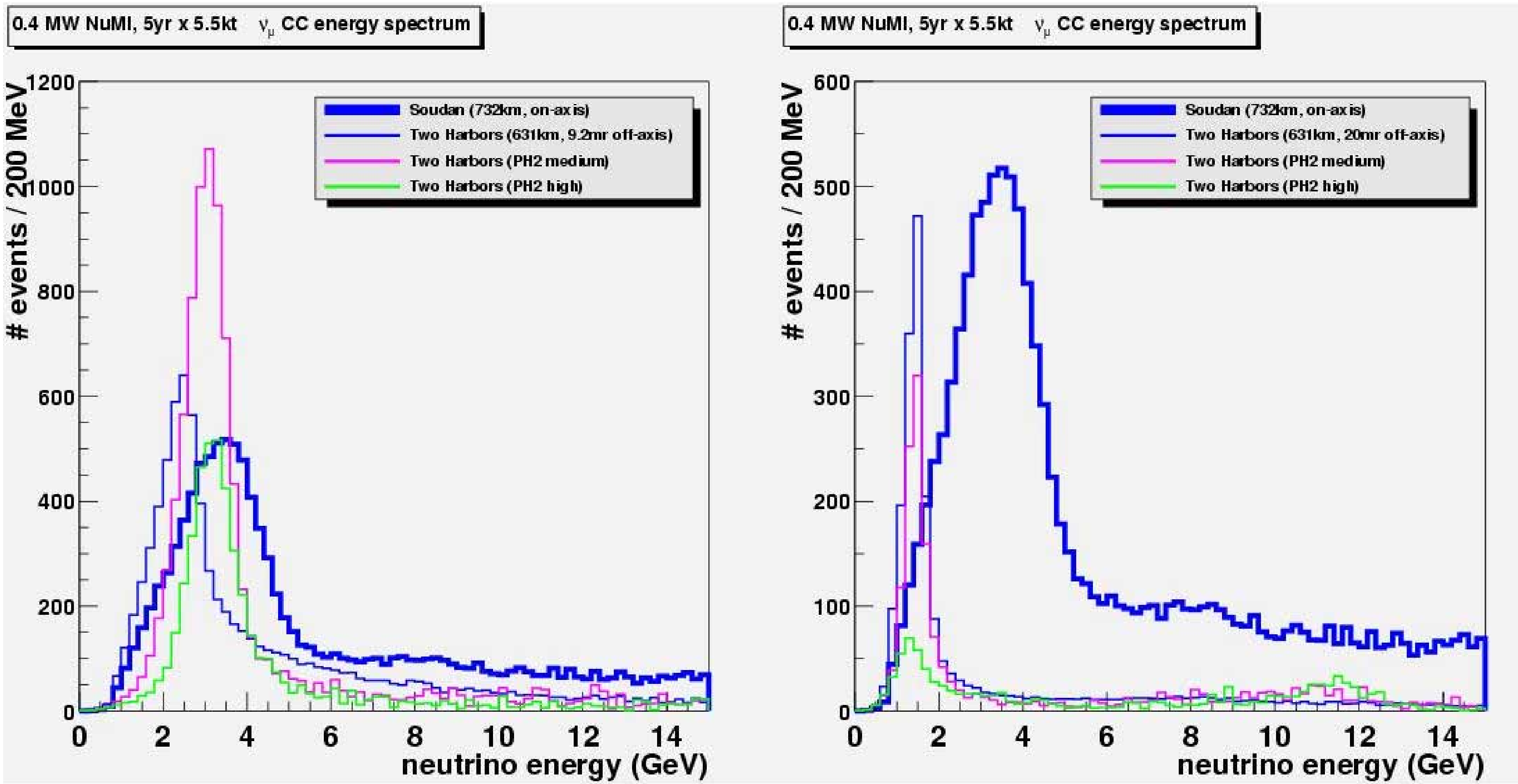
MINOS = 5Ktons

In presence of a PD
Which gives 4 times
More luminosity
We want a detector with
Better capabilities in BG
Rejection than MINOS

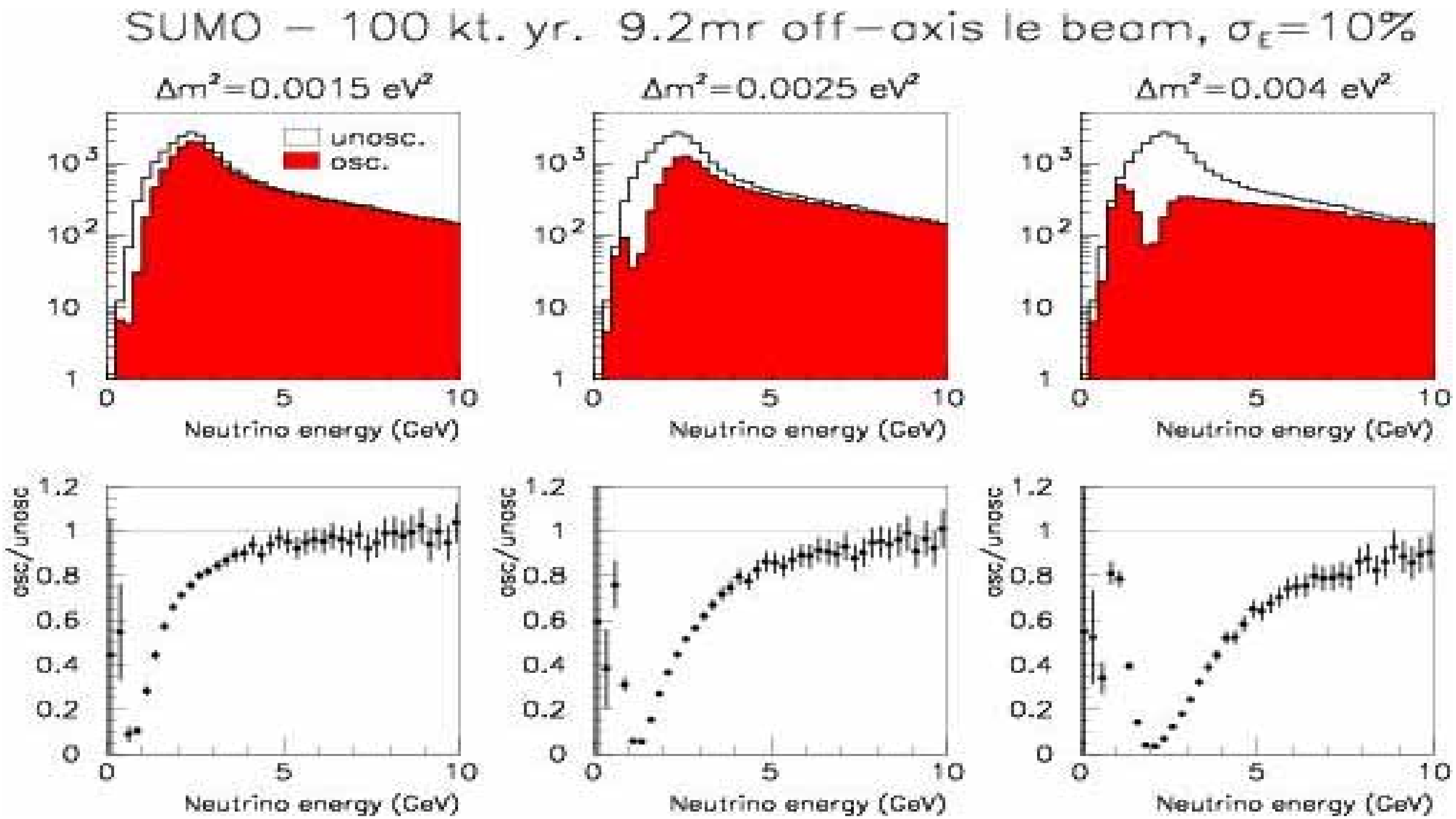
Alternatives…SUMO --20Kton Water (lake) Cherenkov (*L. Wai et al*)



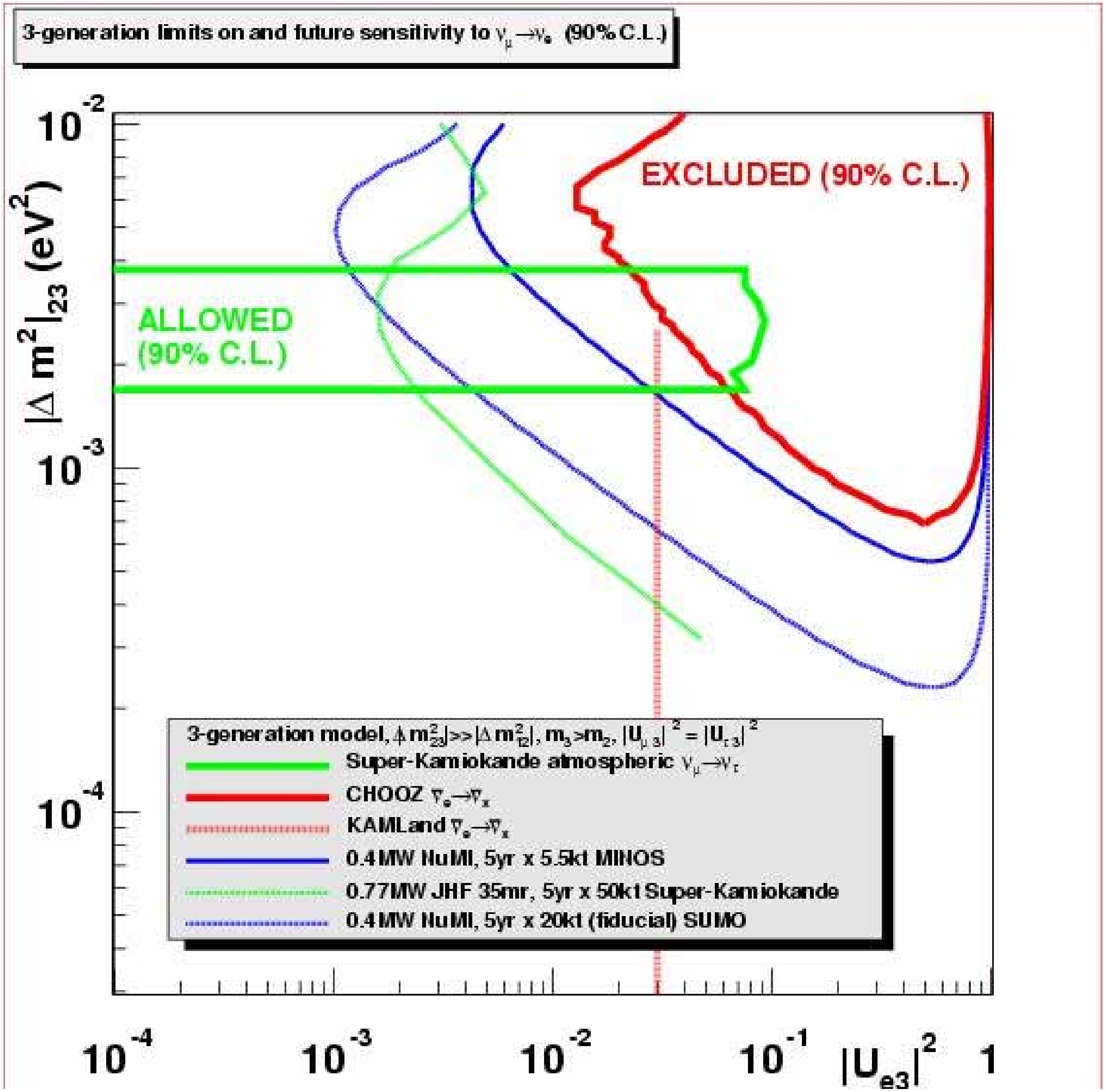
Beam Charactesitics at the lake length (635 km)



SUMO Expectations



Exclusion plots for $|U_{e3}|^2$



What is Next?

- Assume $|U_{e3}|^2$ Observed with/without PD with a SO-MINOS type detector, what kind of measurement of δ can we make running with anti-neutrinos or a new OAB detector with L=400 km.
- Use NUMI beam elements to make a new beamline pointing to Homestake with a PD.

Conclusion

- OAB with the current design of NUMI could provide a good reach in $|U_{e3}|^2$ if we invest in the *proper* detector.

- OAB+PD could expand significantly the reach while continuing to use the same detector.